PSF Reconstruction and Analysis DES Science Verification Data

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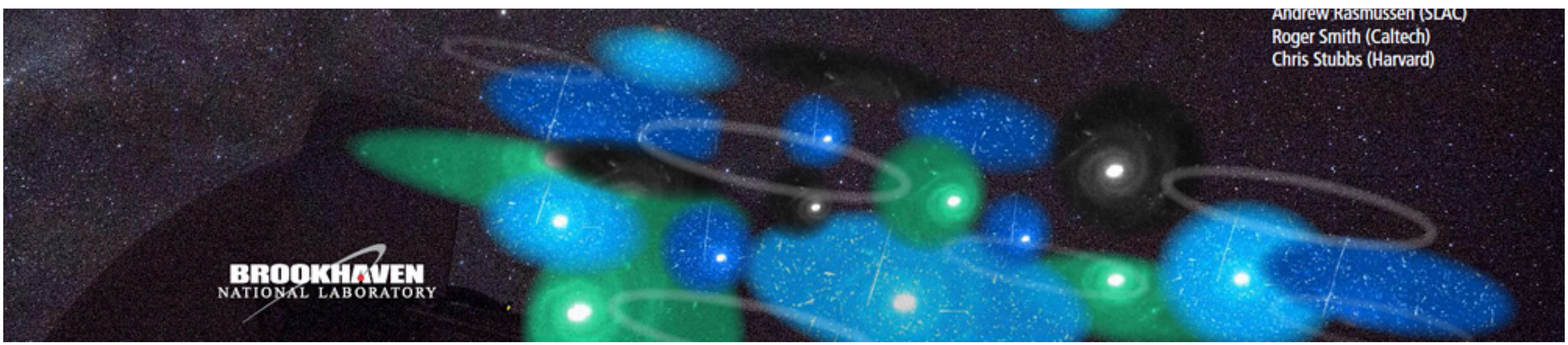


Why should you care about accurate PSF's?

- *Get accurate shapes of galaxies to do cosmology!*
- My biased view comes from working on doing weak lensing on large surveys, but there are there may be other potential applications:
  - Photometry in crowded regions
  - Low surface brightness or barely resolved galaxies
  - Galaxy morphology
  - Accurate astrometry
- The CFHTLens collaboration rejected 25% of their data due to high star-galaxy shape correlation. Source of systematic error was unknown.

What are the important factors

- Optical distortions, abberations
- Atmosphere
- Astrometry
- Brighter-Fatter
- Edge distortions
- Tree rings
- Charge transfer efficiency
- Sampling
- Chromatic Effects

If we can model some these (WCS, chromaticity) before we try to deal with the PSF, it makes our life easier.

PSF Reconstruction

- Use stars in the field to measure samples of the PSF
- PSF Models
  - Analytic form (shapelet, wavelet, Gaussian)
  - Pixel basis
  - Principal component analysis (PCA)
- PSF Interpolation
  - Polynomial
  - PCA
  - Gaussian process
  - Kriging
- A majority of weak lensing analyses have used some combination of PCA and polynomial interpolation with PCA or pixel basis.

Limitations

- Potentially many free parameters
- How do you choose the optimal number of basis functions
- Polynomial
  - Assume data varies smoothly, cannot capture high frequency variations?
- Limitations to generic PCA
  - Missing data and outliers
  - Does not produce a generative model
  - Assumes Gaussian-Linear model
- Variations to standard polynomial and PCA interpolation can accommodate some of these issues.

How well do we need to know the PSF?

- Depends on particular science application
- Weak lensing Survey requirements:
  - Euclid, HSC, DES, LSST have goals to reach accuracy of size and ellipticity to a few tenths of a percent.

Cosmic shear requirements for DES

Error in PSF ellipticity $$\left\langle|\delta\epsilon_p|^2\right\rangle^{\frac{1}{2}} < 2.8\times10^{-3}\left(\frac{P_\gamma}{1.84}\right)\left(\frac{R/R_p}{1.2}\right)^2$$

Error in PSF size $$\left\langle\frac{\delta(R_p^2)}{R_p^2}\right\rangle^{\frac{1}{2}} < 6.9\times10^{-3}\left(\frac{P_\gamma}{1.84}\right)\left(\frac{R/R_p}{1.2}\right)^2\left(\frac{0.4}{(\langle|\epsilon|^2\rangle+\langle|\epsilon_p|^2\rangle)^{\frac{1}{2}}}\right)$$

For full 5 year DES survey factors reduce to

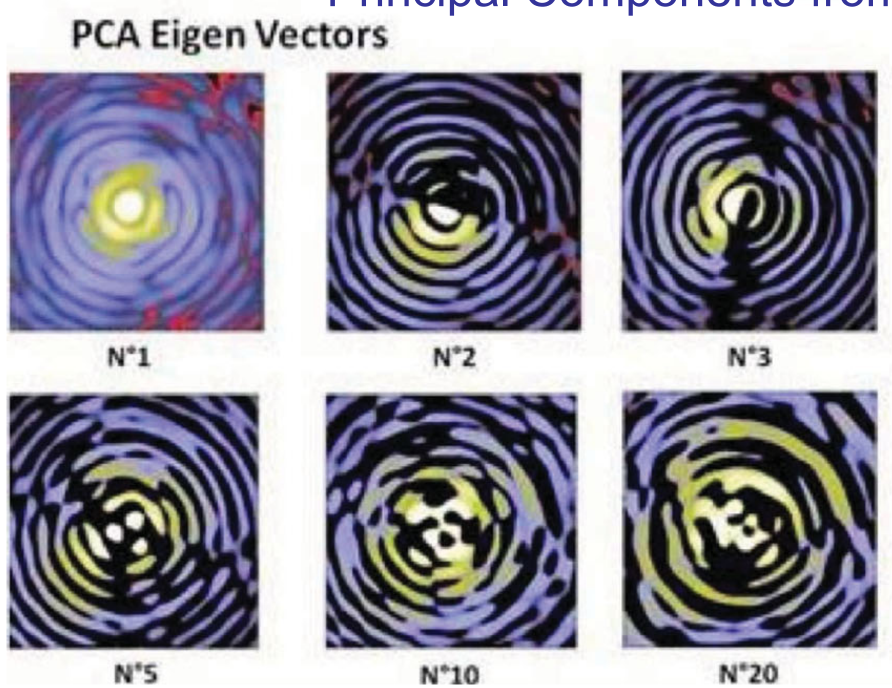
PSF ellipticity -> 1.2×10^{-3}

PSF size -> 3.1×10^{-3} ()

Modeling the optics

- Fairly straightforward to simulate PSF due to telescope misalignment, aberrations using eg. Zemax models.
- Wavefront data can help constrain real data.

Principal Components from Euclid Simulations



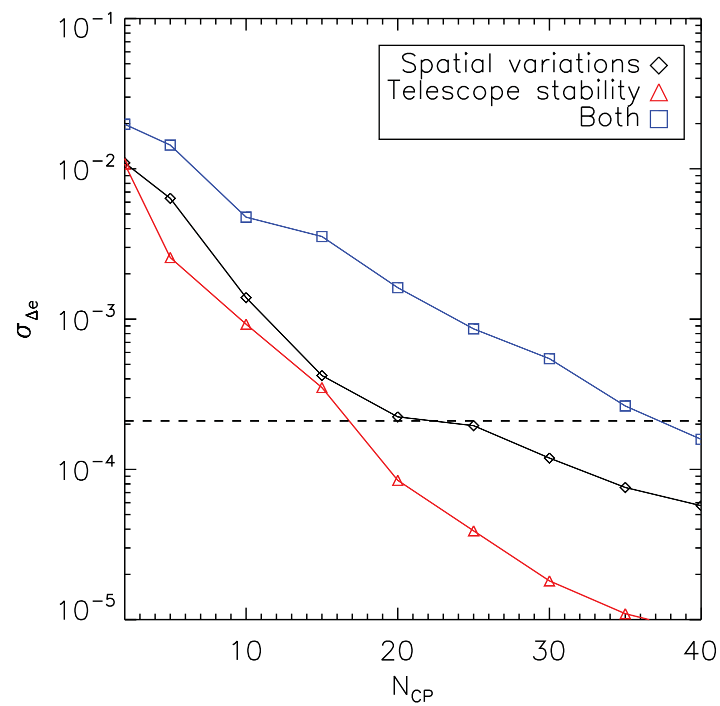
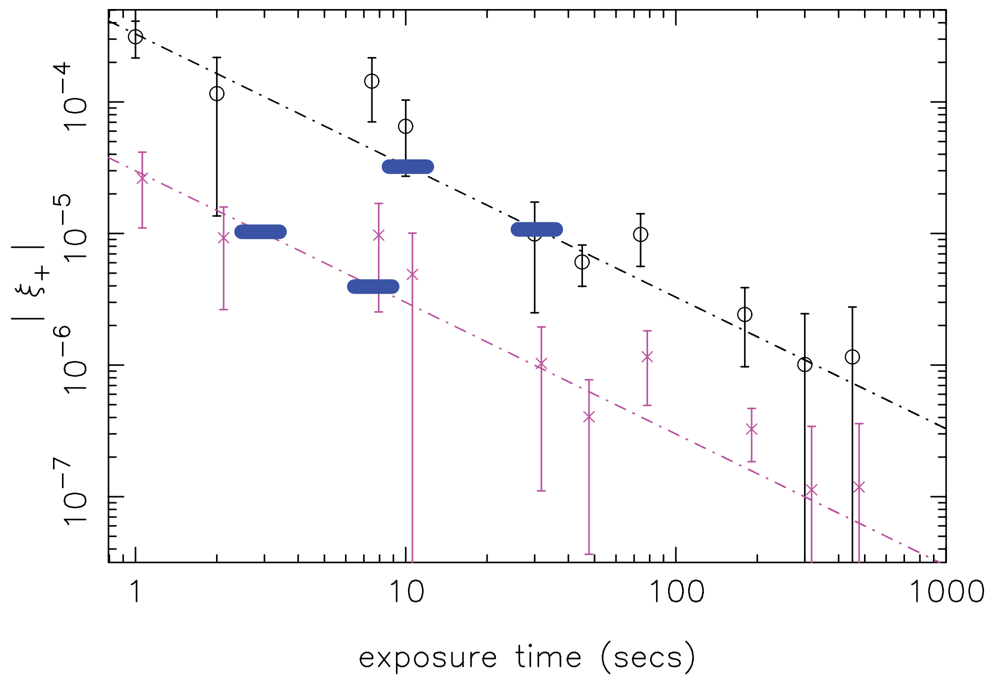


Image Credit: Cropper et. al. 2012

Modeling the Atmosphere

- Atmospheric component scales as (Exposure Time)$^{-1/2}$
- Will be challenging for surveys with high cadence like LSST to model this component. Current focus has been in using simulations to model effects of the atmosphere.

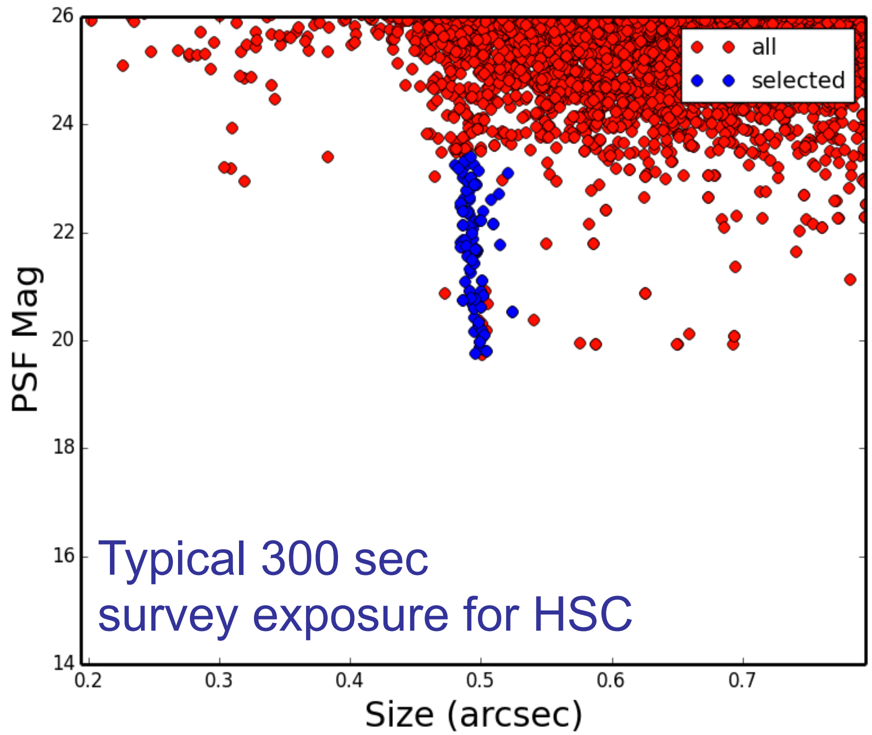


Residual-Residual correlation after polynomial has been subtracted

Image Credit: Heymans et. al. 2012

Star Selection

- Longer exposures mean:
  - More stars are saturated
  - More stars are blended
  - Can push to lower S/N, but need to worry about noisy measurements and bias.
- Can we use barely resolved galaxies from multiple exposures?
- Combine with external information?



More sophisticated interpolation techniques

- The literature is full of potential new methods that can overcome some of the current limitations.
- Have yet to be fully vetted with real data.

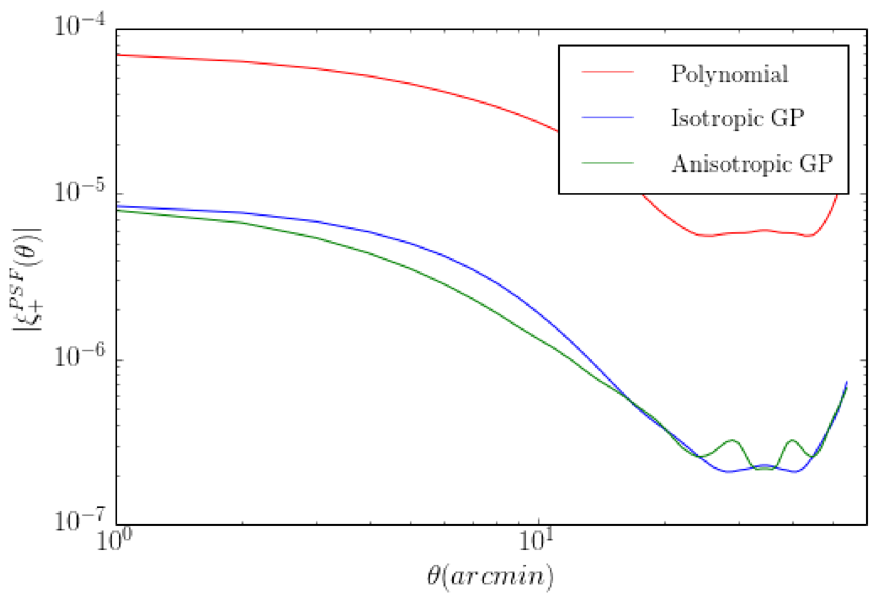


Image Credit: Mohammadjavad Valkili

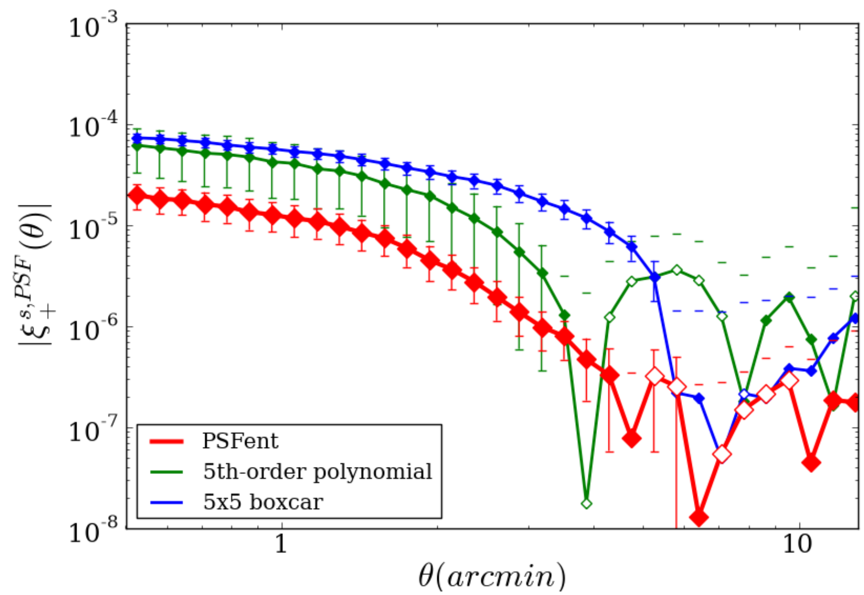


Image Credit: Chang et. al. 2012

The Truth?

- How do you characterize the uncertainty in your estimate of the PSF? Can you predict the posterior and marginalize for science?
- This will depend on how well your basis set can model the PSF.
- Quite a bit of recent work in this area (see Schneider et al. 2014)
- Need to consider computational feasibility.

Probablistic graphical model of shear inference

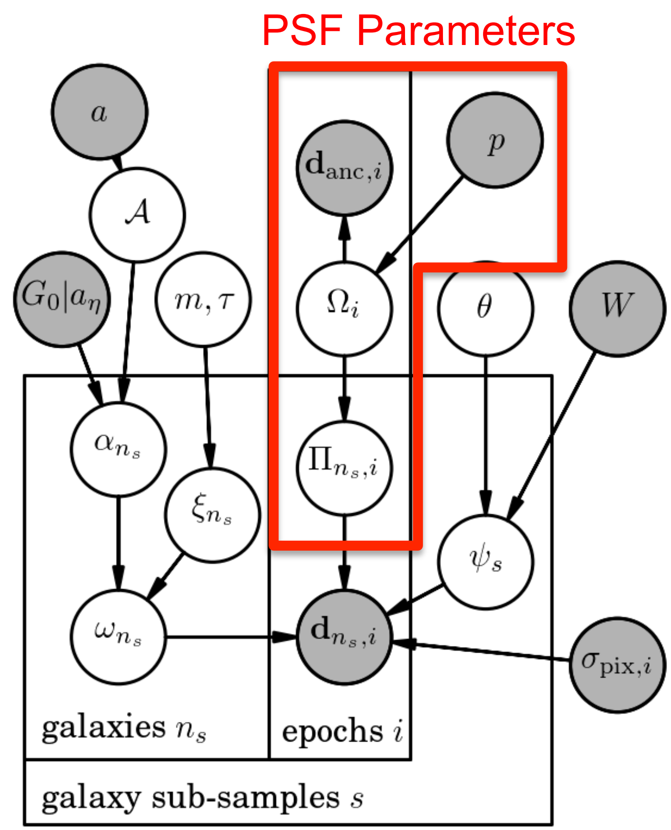
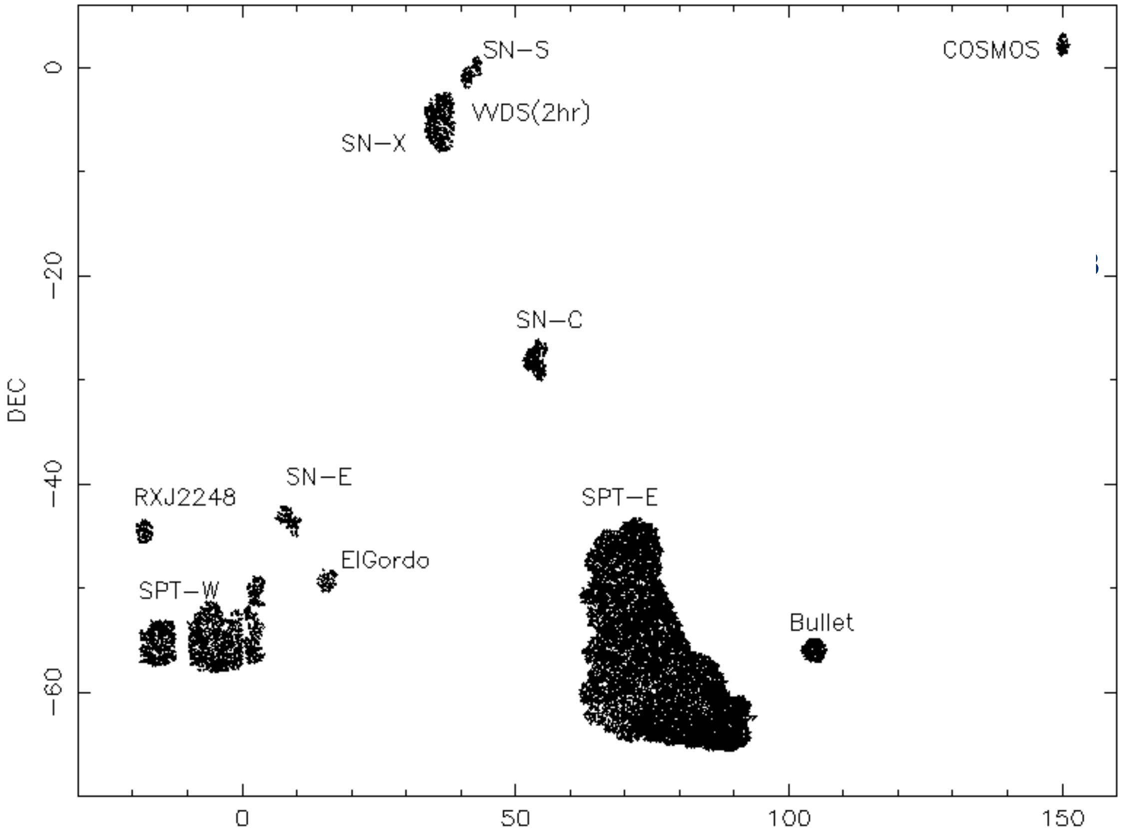


Image Credit: Schneider et. al. 2014

DES Science Verification Data

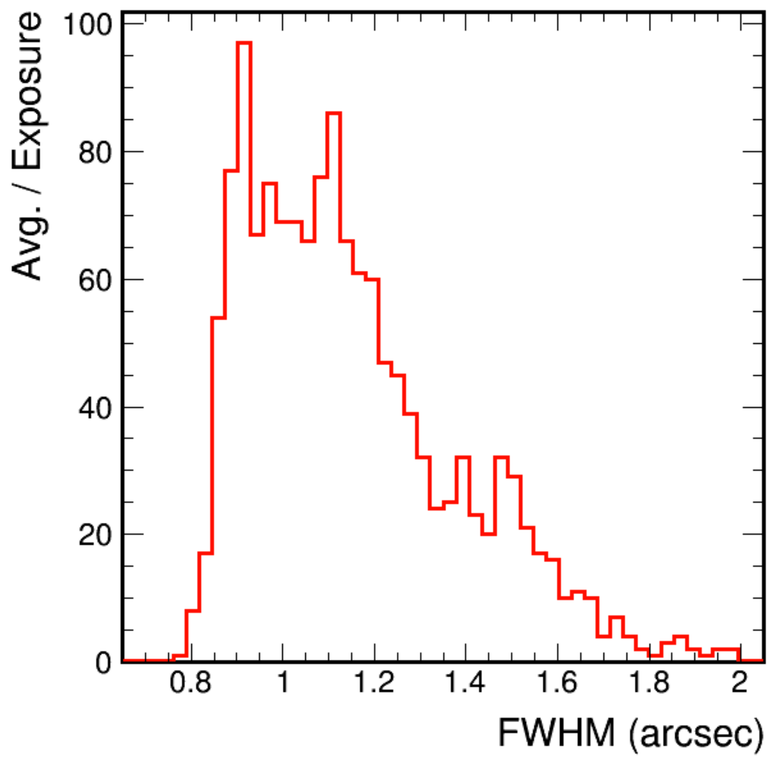
DARK ENERGY SURVEY

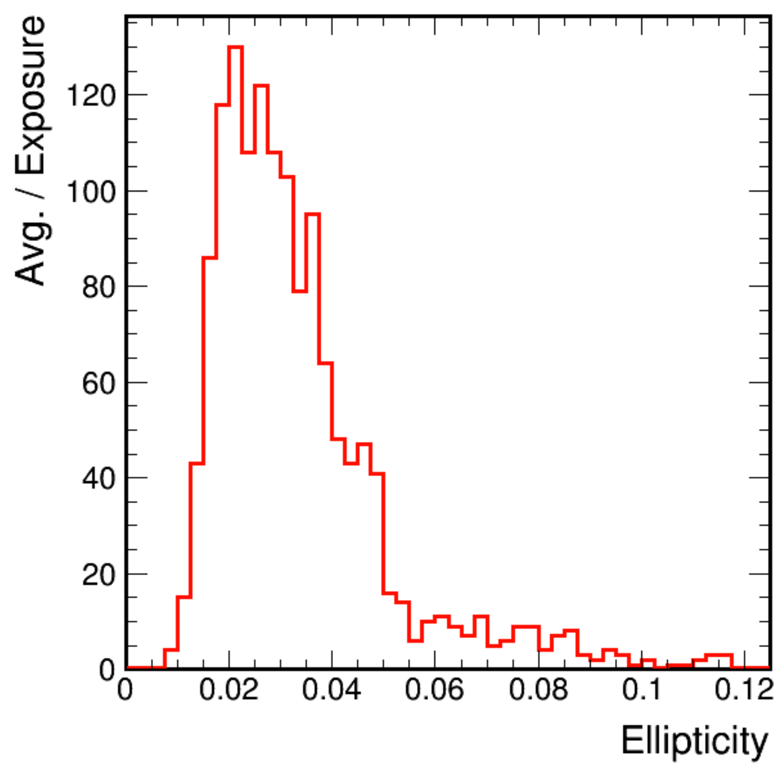


- ~200 sq. deg total
- ~10 million galaxies
- Large contiguous region to depth of ~24 in griz

PSF Characteristics

- Seeing larger than expected, but has significantly improved
- Ellipticity quite small!





PSF Model

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- We use PSFex written by E. Bertin to model the PSF.
- Use an independent reduction from general processing
- Each CCD is modeled independently
  - Input stars are selected using automated algorithm in size vs. mag plane.
  - Remove brightest 3 magnitudes to reduce brighter-fatter effect.
  - Excise regions with known problems.
  - Pixel basis with 2x oversampling.
  - Use 13 arcsec cutouts of stars to avoid truncation.
  - Interpolation uses 2nd order polynomial over CCD to describe spatial variation.

Residual Statistics

- Sufficient number of stars
  - Median ~100 / CCD
- Ellipticity residuals have RMS of 1.7%

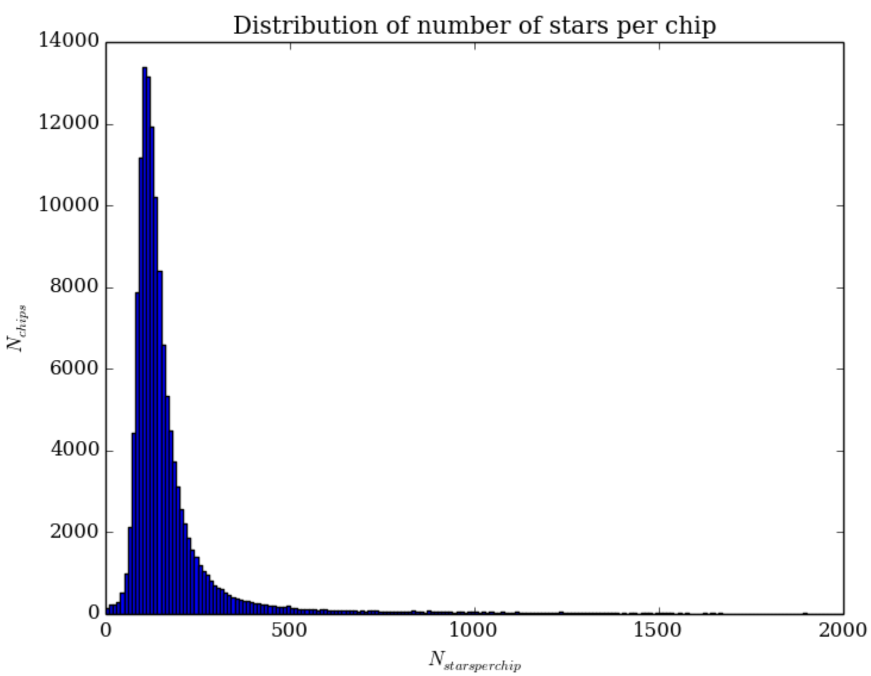
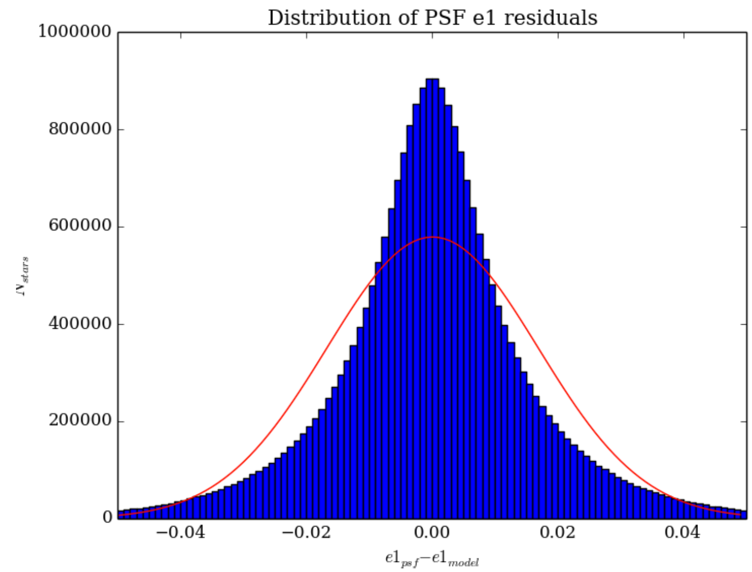
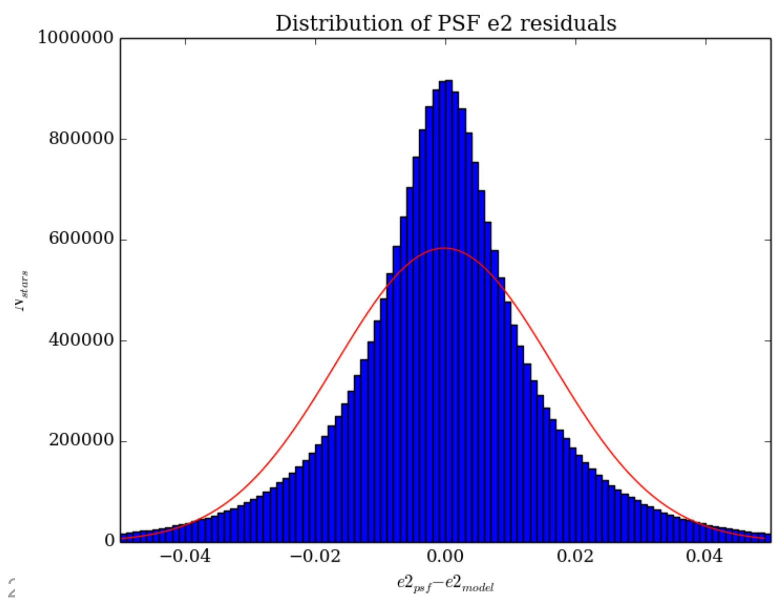


Image Credit: Mike Jarvis





Size Residuals as a function of Magnitude

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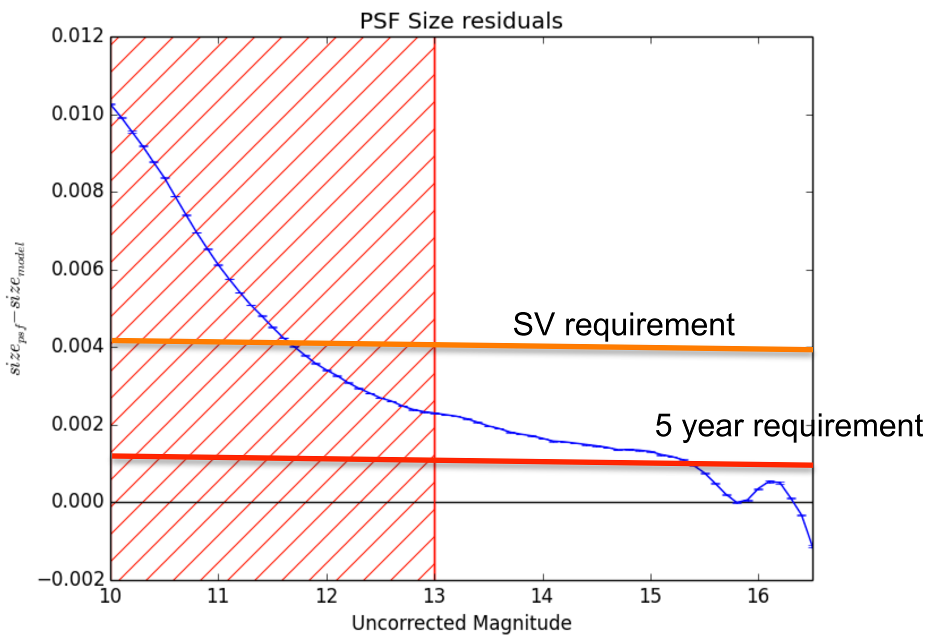
- Deviations below the requirements for SV data
  - Requirements shown for 1” seeing



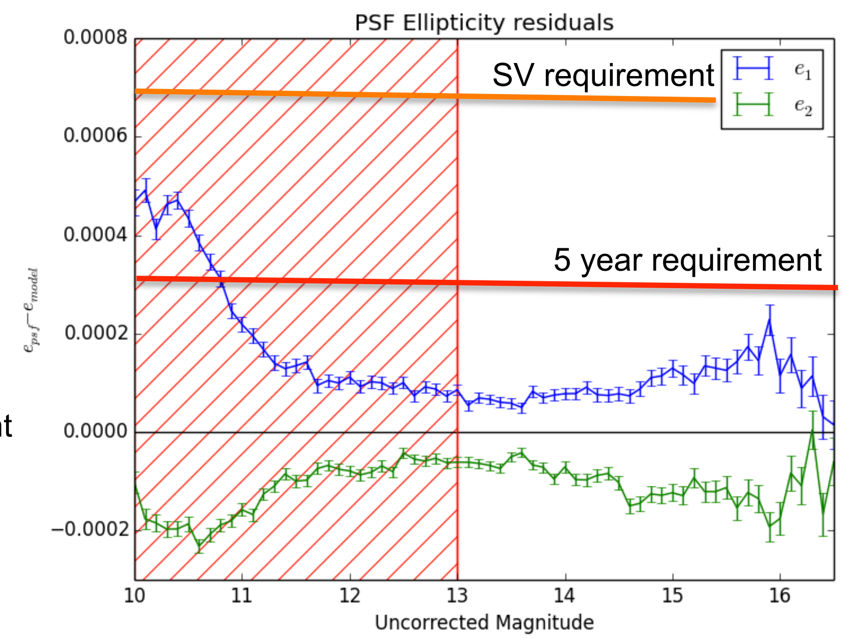


Image Credit: Mike Jarvis

Residuals as a function of chip position

- Deviations as expected and below the requirements

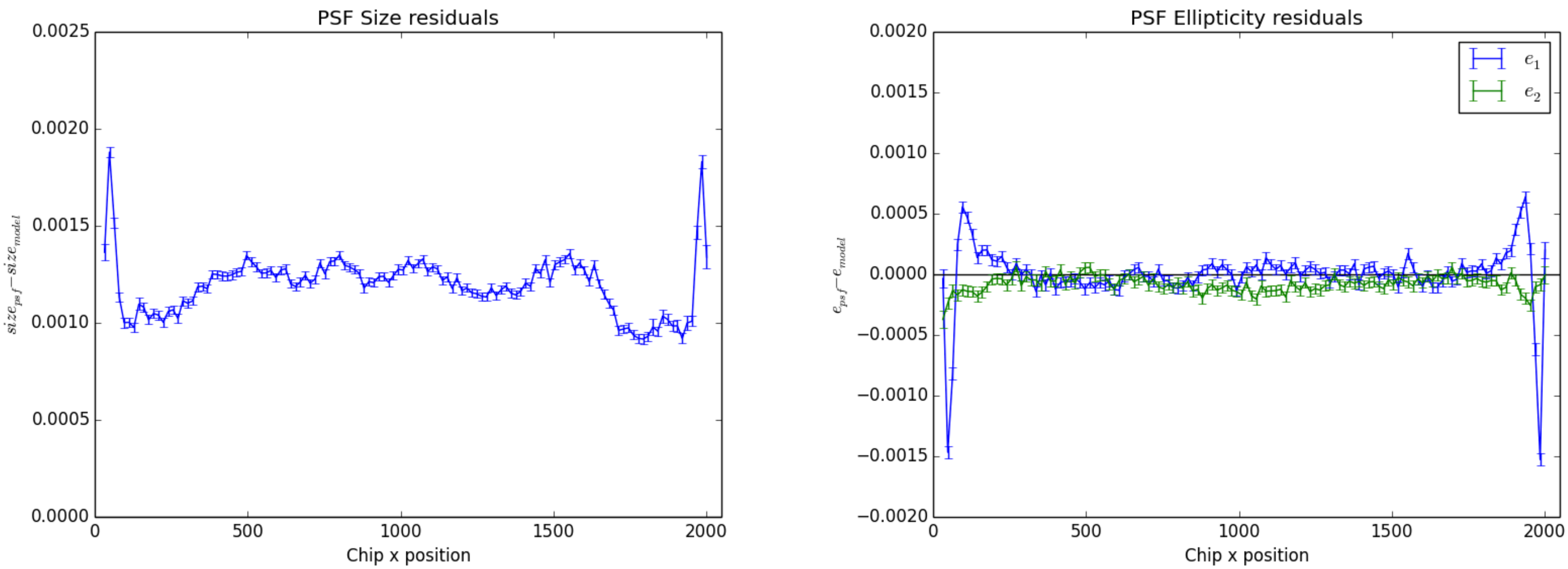


Image Credit: Mike Jarvis

Residuals over Focal Plane

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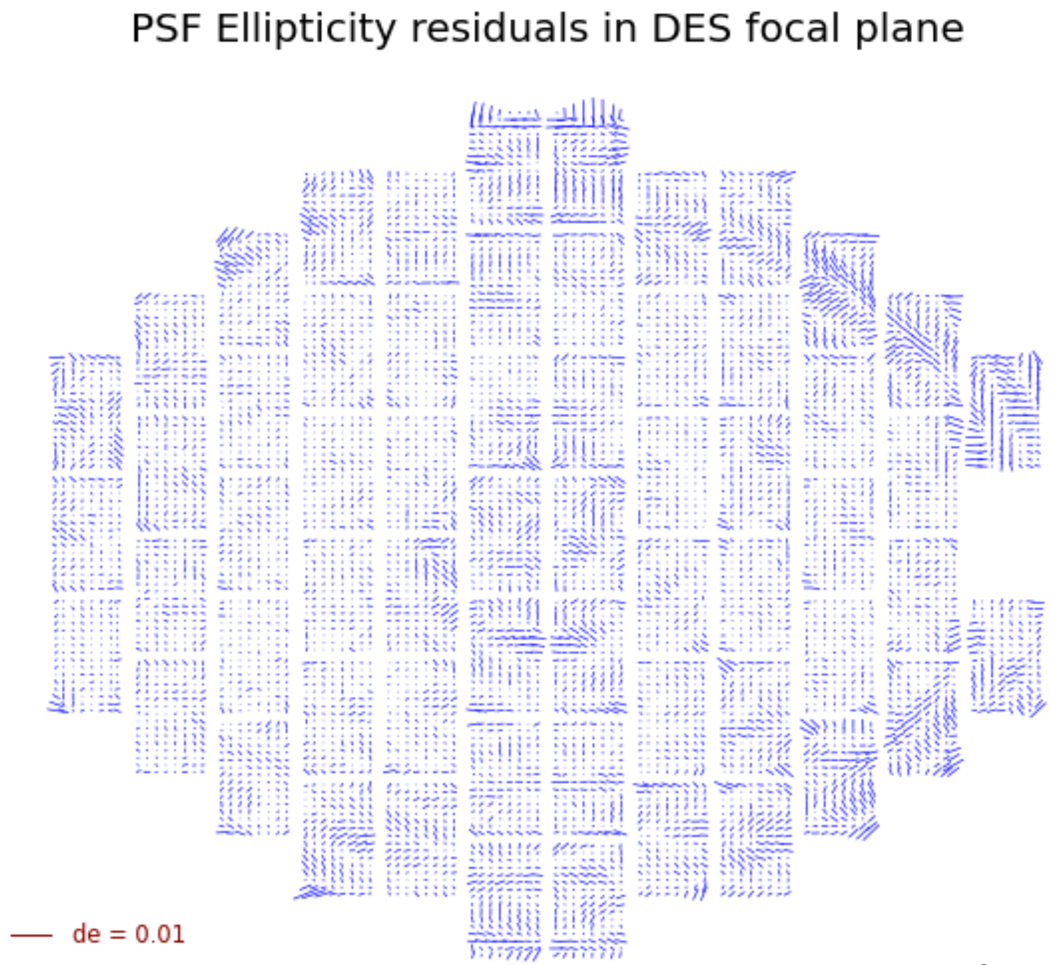


Image Credit: Mike Jarvis

Residual Correlation function

- Correlation of residuals for a single-band
  - Bands show cosmic shear requirements
  - Reduced even further if you combine data from different filters.

Residual – Residual Correlation for *z*-band

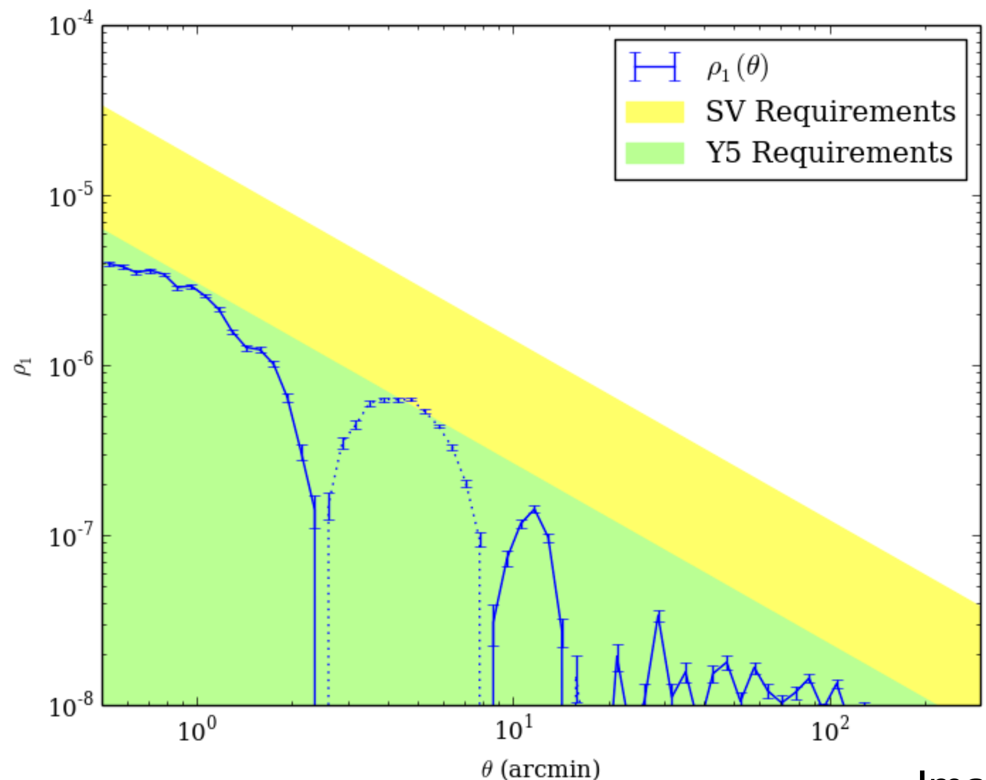


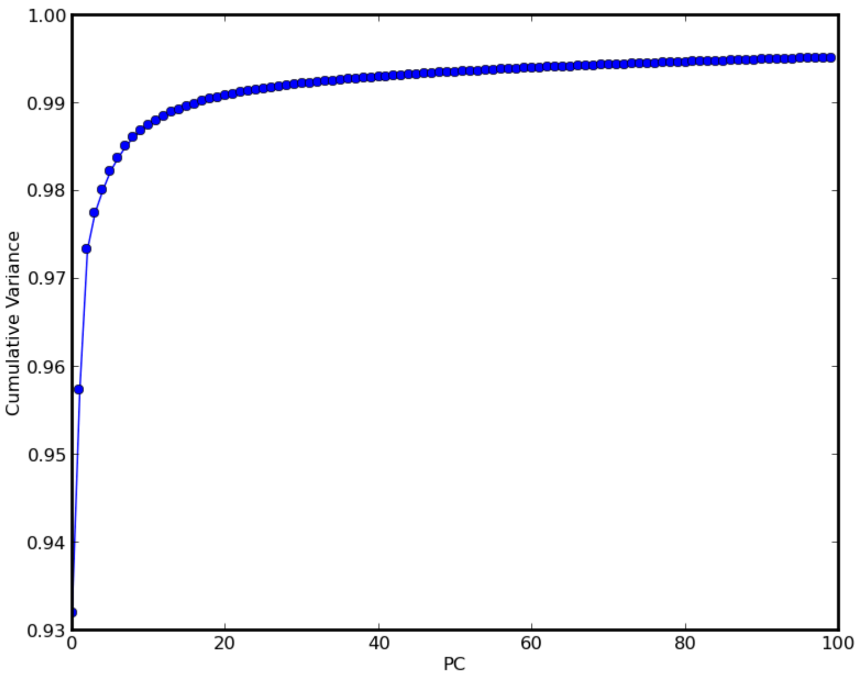
Image Credit: Mike Jarvis

Principal Component Analysis

- Performed a Principal Component Analysis from the same data to look for common patterns across the focal plane
- Purely empirical model that solves for shapelet coefficients in cells over each exposure.
- Could potentially use to diagnose telescope problems?

Majority of variation due to first few principal components: seeing, constant ellipticity

Long tail due to atmosphere?

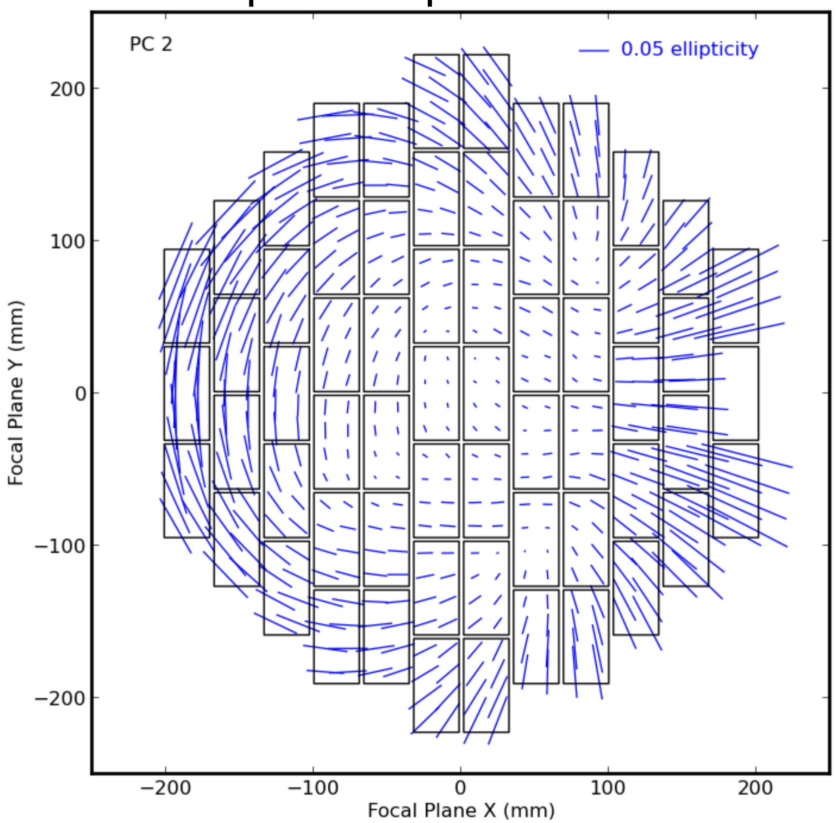


Principal Component Comparison

DARK ENERGY SURVEY

- Comparison of whisker pattern shows similarities for tilt

Principal Component



Calculation of tilt

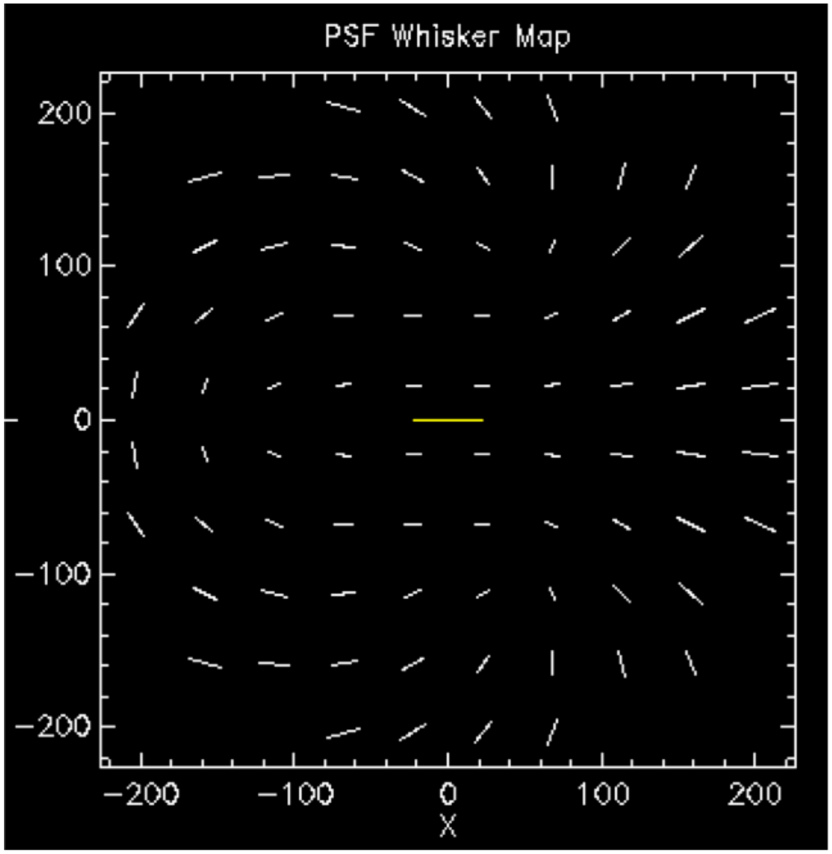
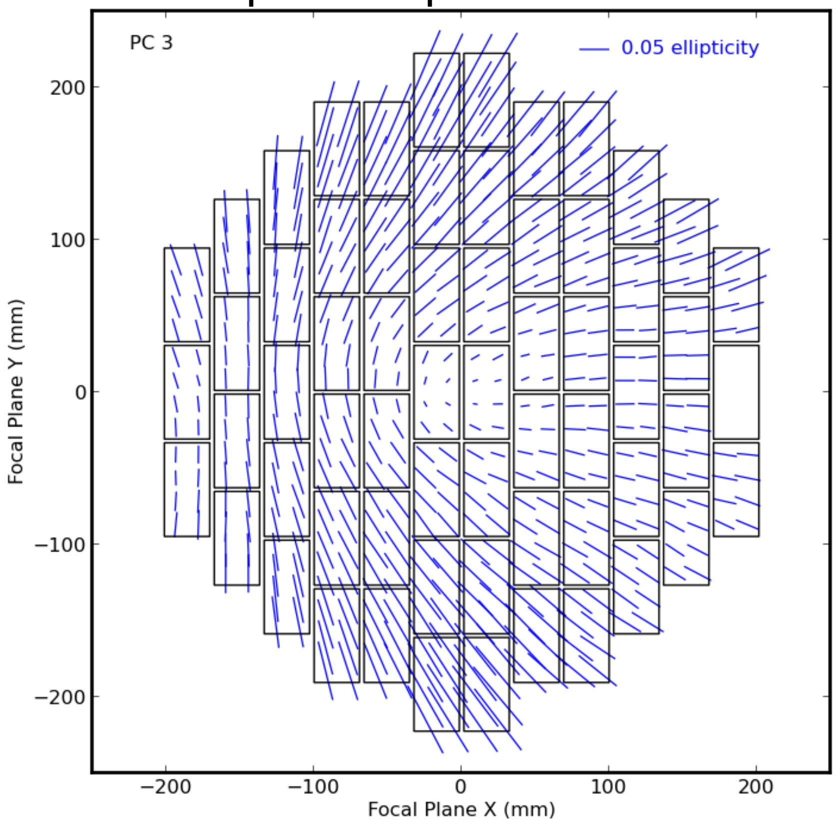


Image Credit: Steve Kent

Principal Component Comparison

- Comparison of whisker pattern shows similarities for decenter

Principal Component



Calculation of decenter

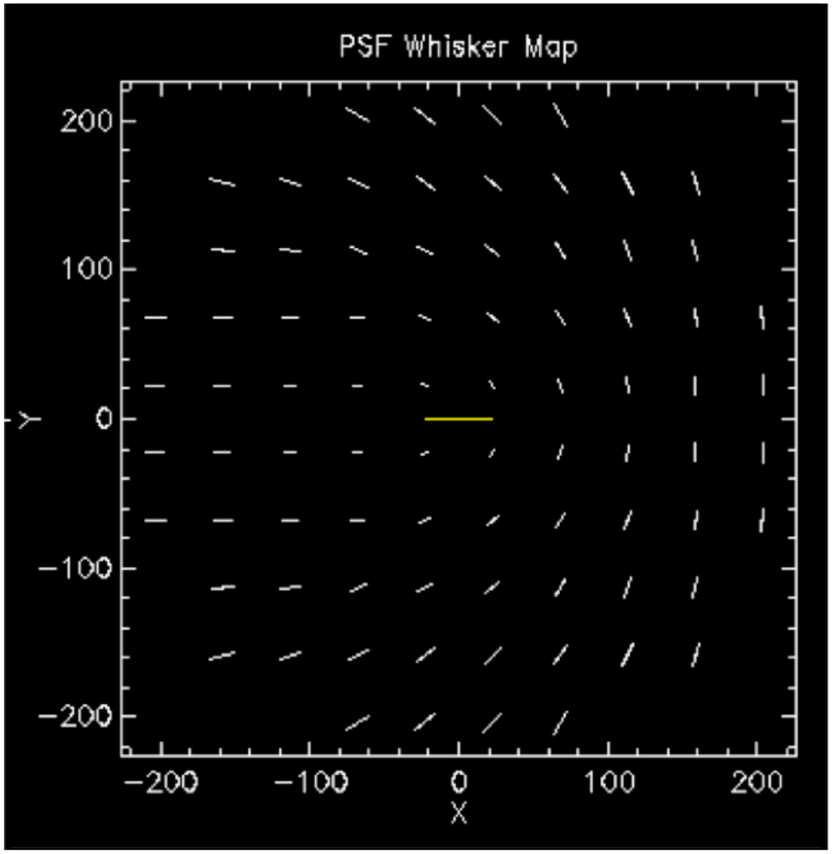


Image Credit: Steve Kent

Beyond an Empirical PCA

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- The PCA did not show an improvement over simple polynomial fit.
- Did not see anything significant correlation between PC and telescope measurements.
- Can probably do better using information from wavefront sensors.

Using Wavefront Sensors

- Aaron Roodman and Chris Davis have been working on wavefront models for the active optics system.
- Fit of PSF stars using wavefront model.
- Hope to combine this with other methods in the future.

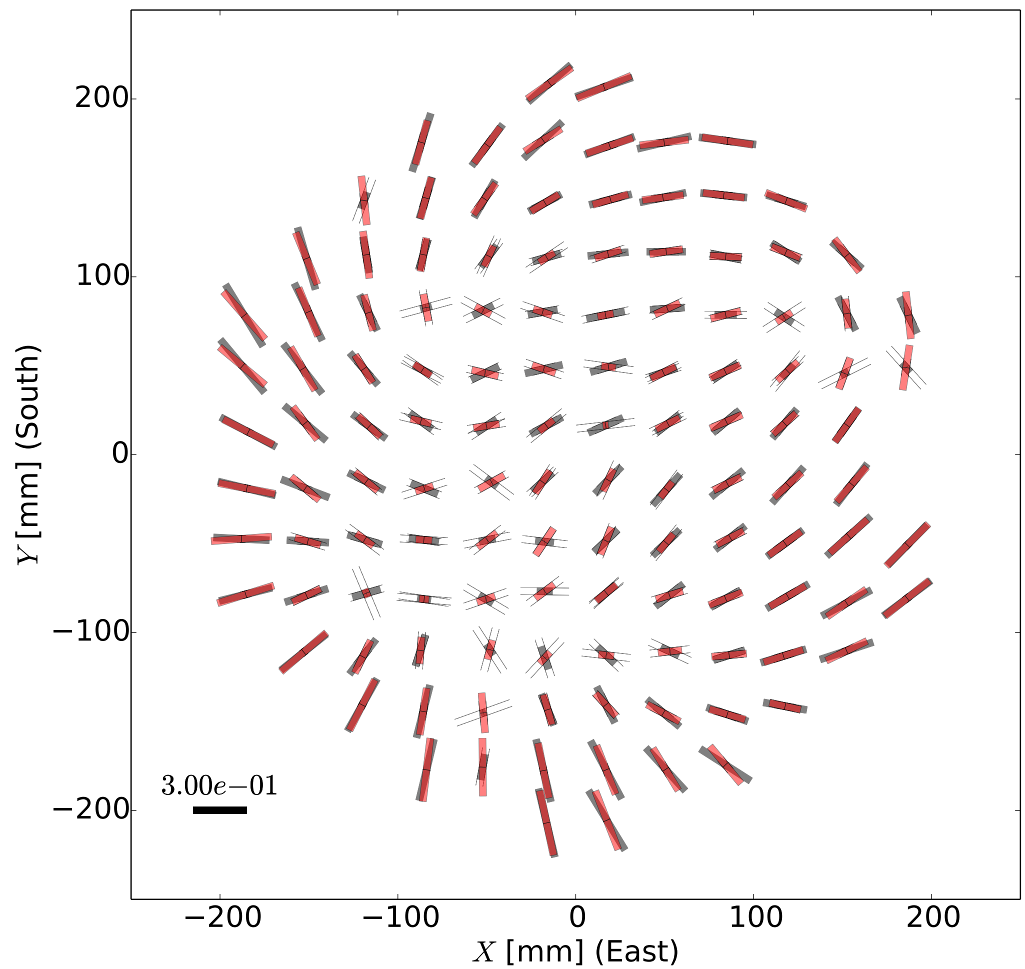

Image Credit: Aaron Roodman

Conclusions

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- Many interesting areas for improvement of PSF modeling
  - Combining optical and atmospheric components
  - Probabilistic PSFs
  - New interpolation methods

- PSF modeling for DES Science Verification is in good shape
  - Simple model/CCD works well
  - Close to meeting requirements for 5 year data
  - Working to incorporate additional features in the model
  - Currently using these models to ensure accurate galaxy shapes

Backup